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CIVIL ENGINEERING

INDIANA
DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

JHRP-86/11

STUDIES ON CONTROLLED LOW STRENGTH MORTAR

William F. Kepler

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

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Final Report

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TO: H. L. Michael, Director
Joint Highway Research Project

August 27, 1986

Project: C-36-61J

FROM: W. L. Dolch
Professor

File: 5-14-10

Attached is the Final Report on the JHRP Study entitled "Studies of Low Strength, High Slump Concrete." The title of the report is "Studies on Controlled Low Strength Concrete." The research was conducted by William F. Kepler, Graduate Assistant in Research, under the direction of Professor W. L. Dolch.

The focus of this research study was the development of mix designs of controlled low strength materials for use in the field as structural backfill in place of soil. The mix designs were developed to satisfy three criteria, compressive strength, flowability, and set time, and included low strength, high strength, air entrained, and light weight materials.

This report is forwarded for review, comment, and acceptance by the IDOH as fulfillment of the objectives of the study.

Respectfully submitted,

W. L. Dolch

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Final Report

STUDIES ON CONTROLLED LOW STRENGTH MORTAR

by

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Joint Highway Research Project

Project No.: C-36-61J

File No.: 5-14-10

Prepared as Part of an Investigation

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ACKNOWLEDGMENTS

The author wishes to thank his major professor, Dr. William L. Dolch, for his guidance in this study. The author also wishes to express gratitude to Dr. Charles F. Scholer for his wisdom and guidance and to Janet Lovell and Joe Walters for their assistance and friendship.

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ABSTRACT

Kepler, William Forrest. M.S.C.E., Purdue University, August 1986. Studies on Controlled Low Strength Mortar. Major Professor: William Dolch.

Soil as a structural backfill is not perfect. It is difficult and costly to place in enclosed spaces, i.e. trenches. Controlled low strength material is a flowing mortar that does not require expensive equipment for placement. It does not have problems with densification during construction, or settlement after construction.

There are no standard mix designs and specifications for the state of Indiana. This study looks at those specifications under consideration elsewhere and proposes some mix designs within such specifications within Indiana. The mix designs can be used in the field in any area where soil is used as a structural backfill and where economy, time, and strength are important factors.

The mix designs were developed to satisfy three criteria: compressive strength, flowability, and set time. The mixes designs include low strength (100 psi), high strength (1000 psi), air entrained, and light weight (50 pcf) materials.

INTRODUCTION AND LITERATURE REVIEW

Controlled Low Strength Mortar (CLSM) is an inexpensive highly flowable low strength mortar used as a low cost alternative to structural backfill in utility cuts and culvert placement. It is made up of cement, sand, and water, and it can also contain industrial by-products such as fly ash. CLSM is low strength so that it can be removed easily. It is highly flowable to allow ease of construction and does not require consolidation. It will easily flow into inaccesable spots, flowing under and around pipe to provide perfect bedding. The mortar gains enough strength so that within 24 hours a pavement can be placed over it. The prime attraction is its low cost, since it is mainly made up of sand and water with little cement and is cheaper than soil as a structural backfill. It can be used in any area where structural backfill is required. Its main uses to date are in utility cuts and street repair. Although the concept of using low strength concrete as fill is old, the development of specifications is just beginning. This study looks at those specifications under consideration and proposes some mix designs within such specifications. The mix designs developed are specifically for materials found in Indiana.

Low strength concrete as backfill is nothing new; almost every engineer has used it at one time another. The new idea is that this mortar is highly flowable with little segregation. The Iowa Department of Transportation has used CLSM while replacing bridges with culverts (1). Metropolitan Toronto Roads and Traffic Department department has done a lot of work in its use as backfill in utility trenches (2). In Indiana the city of Evansville is beginning to use it in their street repair (3).

In this study locally available materials common to most of Indiana and the midwest were used. The materials include: type I cement, concrete sand, class F fly ash, class C fly ash, and chemical admixtures such as air entrainer and accelerator. The mix designs developed for this report are a general guide, with modifications as required in the field. Variables in these mix designs include the particle size gradation of the sand and fly ash, the reactivity of the fly ash, and the type of the chemical admixtures. The mortar was mixed in one cubic foot batches in a four cubic foot mortar mixer. Variability could be induced if the mortar is mixed in other mixers with different types of mixing action. The following properties were measured in this study: Compressive strength (ASTM C-39), Flow time (ASTM C-939), Set time (ASTM C-403),Bleeding (ASTM C-232), and Unit weight (ASTM C-138). For a list of tests and complete titles see Appendix B.

EXPERIMENTAL WORK

Materials

The materials used in this study were Type I cement, Class F and Class C fly ash, concrete sand, accelerator, air entrainer, and a foaming agent. The Type I cement was locally available. The fly ash was supplied by the American Fly Ash Co.. The concrete sand was locally available. It has a fineness modulus of 2.9 . The accelerator was Master Builders, Inc. Pozzolith 122-HE . The air entrainer was Master Builders Vinsol Resin (MBVR). The foam liquid concentrate was supplied by The Mearl Corporation. (See tables 1 to 4 for chemical and physical analysis of materials.)

Equipment

The foam generator, also supplied by The Mearl Corporation, was a Model OT10-3, with a delivery rate of 2.82 cubic feet per minute and a 10 gallon capacity. The foam concentrate was premixed 1:40 (by volume) with clean water. This solution was expanded 20 times with air. The foam had a final density of 3.12 pounds per cubic foot.

The testing equipment complied with the ASTM requirements for the procedures used. The testing machine was a Satek mechanical machine with a capacity of 120000 lb and a digital readout to the nearest pound.

Mixing Procedure

The mixing was done in a 4 cubic foot, Stow, electric powered mortar mixer. The mixer was turned on, then the sand, fly ash, and cement were added. The water and any admixtures, including the foam, were then added and the mortar was allowed to mix for three minutes. At that time mixing was stopped and testing began.

First the flow time was measured, then 3"x 6" cylinder compression strength samples were made. Then specimens for penetration resistance and bleeding were made and set aside. Finally the unit weight sample was taken.

Testing Procedure

The 3"x 6" cylinders used for compressive strength testing were made in accordance with ASTM C-192, with the following exceptions: the mortar was not consolidated by either rodding or vibration, and the cylinders were allowed to sit covered in the lab for 72 hours before stripping.

The compressive strength determination of the mortar was done in accordance with ASTM C-39. Each mortar mix had testing done at 3 days, 7 days and 28 days. The compressive strength results are the average of three cylinders.

The flow time of the mortar was determined according to ASTM C-939

The bleeding test was done in accordance with ASTM C-232 (Method A), with the following exceptions: the containers used were 6" dia x 7" cylindrical food cans, and the sample was not consolidated with rodding or vibration.

The unit weight, yield and air content were determined by ASTM C-138, with the following exceptions: the container was 1/10th cubic foot in volume, and the mortar was not consolidated by rodding or vibration.

Penetration Resistance was measured according to ASTM C-403. Due to the low strength of CLSM the criteria for set as required by ASTM C-403 does not apply. Testing was done until penetration resistance reached 1000 psi or for 24 hours. Set time for this material is subjective until more testing can be done in the field.

Table No. 1

Concrete Sand Sieve Analysis

Sieve size	Percentage Retained
3/8"	0.0
# 4	0.5
# 8	15.5
# 16	19.5
# 30	21.9
# 50	30.3
# 100	11.1
Pass 100	1.1

F.M. = 2.9

Compact Unit Weight = 96.1 pcf

Loose Unit Weight = 83.8 pcf

Bulk Specific Gravity = 2.57

Bulk Specific Gravity (saturated-surface dry) = 2.62

Apparent Specific Gravity = 2.70

Absorption = 1.83%

Table No. 2

Chemical and Physical Analysis of Cement

Identification: Type I — Purdue Reference: # 326
Source: Lone Star Industries, Inc. — Greencastle, Indiana
Date of testing: June 11, 1985

Chemical Analysis	
SiO_2	20.98
Al_2O_3	5.38
Fe_2O_3	2.46
CaO	64.34
MgO	1.09
SO_3	3.03
Na_2O	0.09
K_2O	0.72
T.A. as Na_2O	0.56
Ignition Loss	1.40
Insoluble Residue	0.23
Potential Compound Composition	
C_3S	54.14
C_2S	19.39
C_3A	10.10
C_4AF	7.47
$CaSO_4$	5.15
Physical Tests	
Normal Consistency	25.0%
Expansion	0.011%
Air Entrained	9.7%
Setting Time	
Gilmore (hr:min)	
Initial	1:55
Final	3:50
Vicat I/F (min)	85/180
Fineness	
325, % Passing	83.7
Wagner, cm2/g	1730
Blaine, cm2/g	3275
Compressive Strength (psi)	
1 day	2140
3 days	3430
7 days	4290
28 days	5380

Table No. 3

Chemical and Physical Analysis of Class F Fly Ash

From: American Fly Ash Company

Source: Schahfer Unit 17

Date of Testing: June 1985

Loss on Ignition	1.66%
SO_3	1.17%
$SiO_2/Al_2O_3/Fe_2O_3$	90.9 %
KaO/MgO	4.72 / 1.11 %
Available Alkalies as Na_2O	2.16%
Pozzolanic Activity with portland cement, strength at 28 days, % of control	79
Water requirement % of control	94
Autoclave expansion, %	0.06
No. 325 sieve residue, %	32.5
variation, percentage points from average	5.0
Specific gravity	2.47
Variation from average	0.0

Table No. 4

Chemical and Physical Analysis of Class C Fly Ash

From: American Fly Ash Company

Source: Rockport Unit 1

Date of Testing: July 1985

Loss on Ignition	0.14%
SO_3	2.38%
$SiO_2/Al_2O_3/Fe_2O_3$	65.0 %
KaO/MgO	25.8 / 6.05 %
Available Alkalies as Na_2O	2.64%
Pozzolanic Activity with portland cement, strength at 28 days, % of control	124
Water requirement % of control	89
Autoclave expansion, %	0.07
No. 325 sieve residue, %	11.5
variation, percentage points from average	3.9
Specific gravity	2.75
Variation from average	1.1

DATA AND RESULTS

The following are typical mix designs developed in this study and some of their properties. Although there were a number of mixes tested, the data presented are the result of only one batch per mix design.

Mix Designs

1) Low strength mortar with class F fly ash

Mix design for one cubic yard

61 lb. cement
331 lb. fly ash
2859 lb. sand
509 lb. water
3760 lb. total

w/c = 8.34
w/c+f = 1.30

2) Accelerated low strength mortar with class F fly ash

Mix design for one cubic yard

61 lb. cement
331 lb. fly ash
2859 lb. sand
509 lb. water
36 oz Pozzolith 122-HE
3760 lb. total

w/c = 8.34
w/c+f = 1.30

3) Air entrained low strength mortar

Mix design for one cubic yard

185 lb. cement
2673 lb. sand
500 lb. water
5.2 oz MB-VR
3358 lb. total

w/c = 2.70

Note this mix design has an air content of 10% by ASTM C-138

4) High strength mortar with class F fly ash

Mix design for one cubic yard

195 lb. cement
572 lb. fly ash
2673 lb. sand
488 lb. water
3723 lb. total

w/c = 2.50
w/c+f = 0.64

5) Accelerated high strength mortar with class F fly ash

Mix design for one cubic yard

195 lb. cement
572 lb. fly ash
2673 lb. sand
488 lb. water
45.2 oz Pozzolith 122-HE
3723 lb. total

w/c = 2.50
w/c+f = 0.64

6) Low strength mortar with class C fly ash

Mix design for one cubic yard

A)

27	lb. cement
635	lb. fly ash
2741	lb. sand
407	lb. water
3810	lb. total

w/c = 15.1
w/c+f = 0.61

B)

41	lb. cement
508	lb. fly ash
2640	lb. sand
508	lb. water
3697	lb. total

w/c = 12.4
w/c+f = 0.93

7) Low strength light weight mortar

Mix design for one cubic yard

517	lb. cement
413	lb. sand
341	lb. water
52.6	lb. foam = 16.85 cft
1324	lb. total

w/c = 0.66

Table No. 5

Flow Time, Unit weight and Bleeding

Mix design	Flow Time	Unit Weight	Bleeding
1	n/a	139 pcf	27.3%
2	n/a	138 pcf	11.6%
3	n/a	125 pcf	14.3%
4	33 sec	138 pcf	15.3%
5	31 sec	139 pcf	13.3%
6 a	n/a	141 pcf	none
6 b	14 sec	137 pcf	4.1%
7	29 sec	49 pcf	none

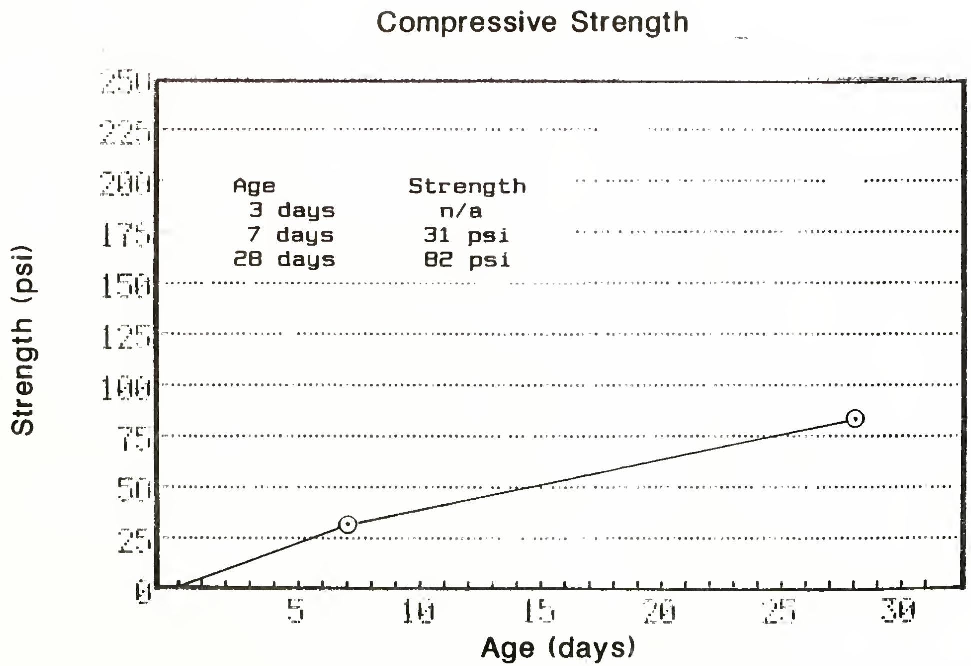

Figure No. 1. Compressive Strength, Mix No. 1

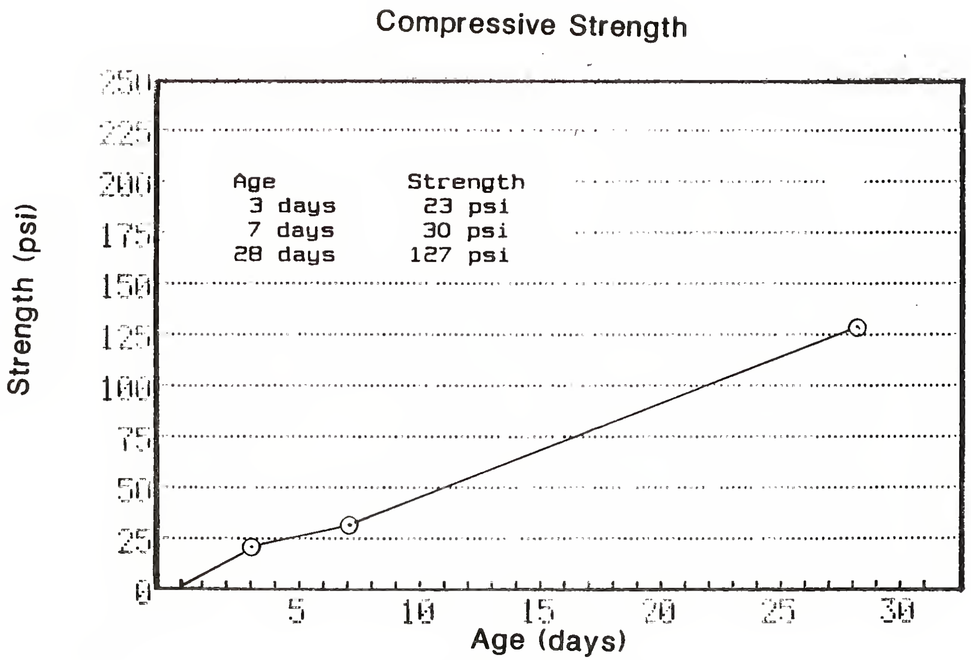

Figure No. 2. Compressive Strength, Mix No. 2

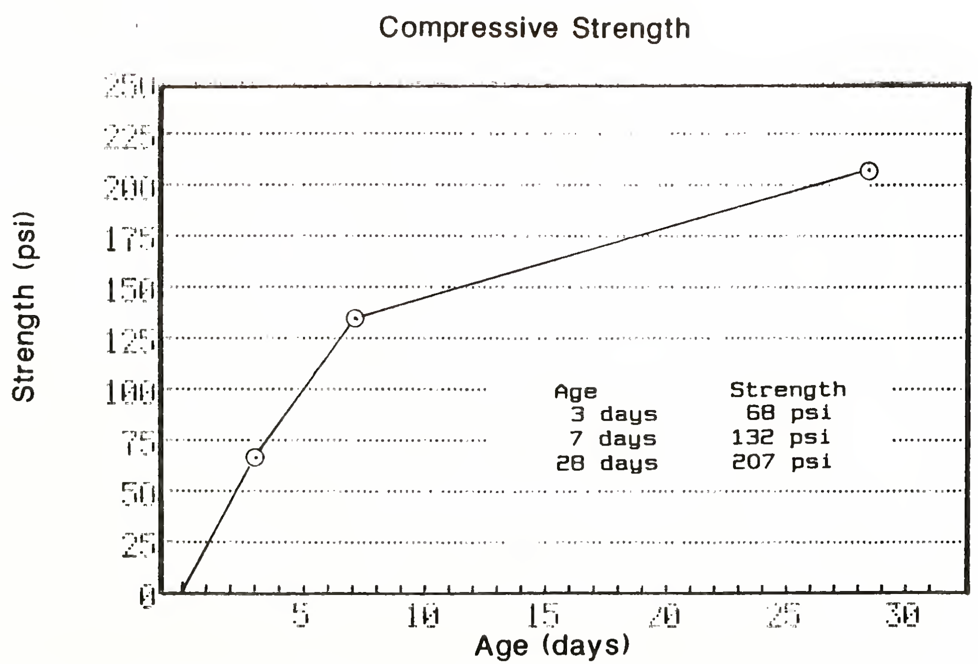

Figure No. 3. Compressive Strength, Mix No. 3

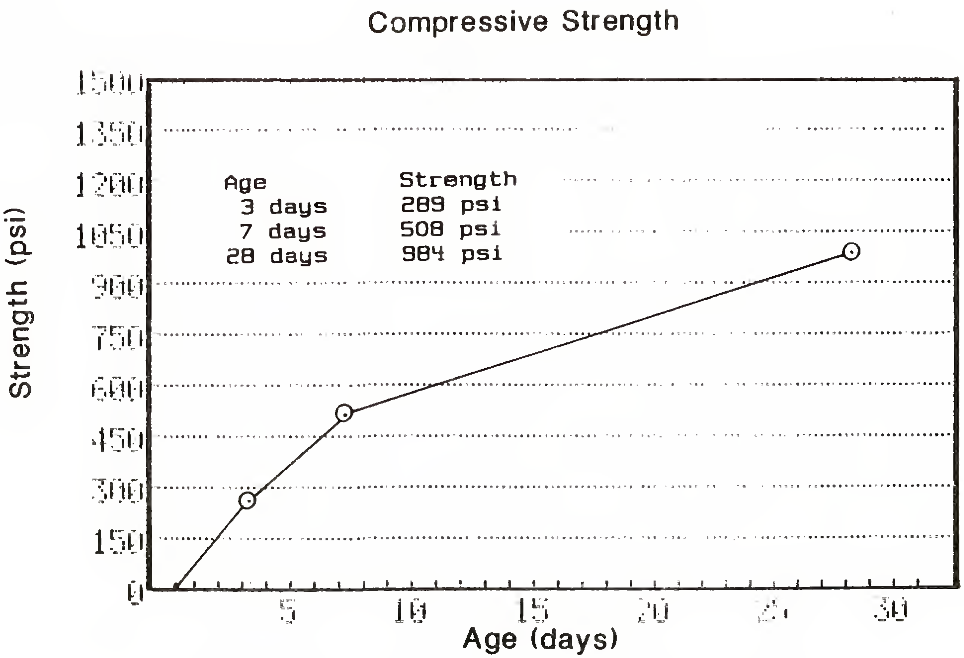

Figure No. 4. Compressive Strength, Mix No. 4

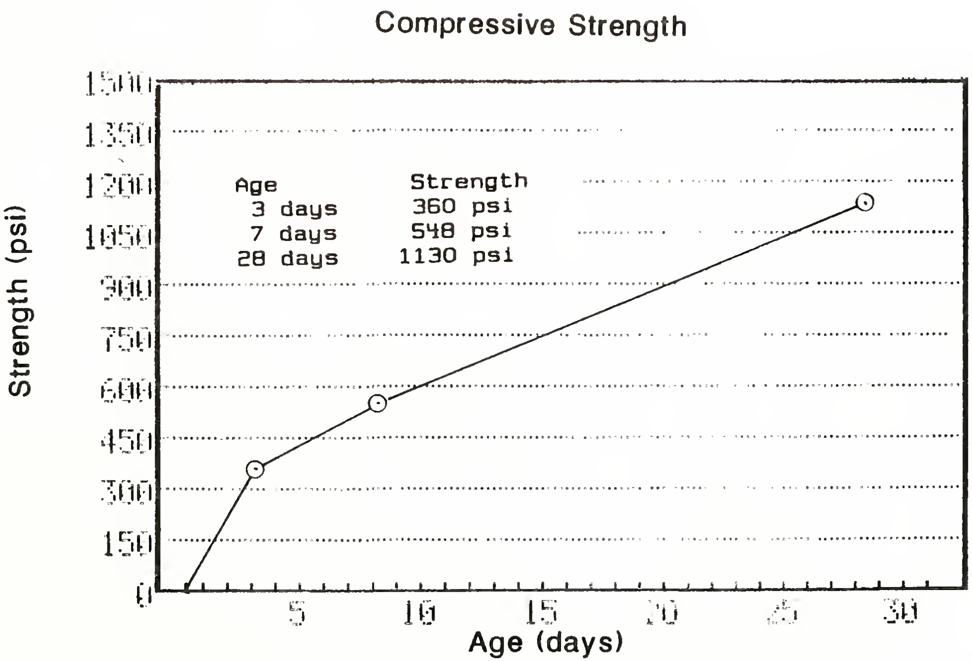

Figure No. 5. Compressive Strength, Mix No. 5

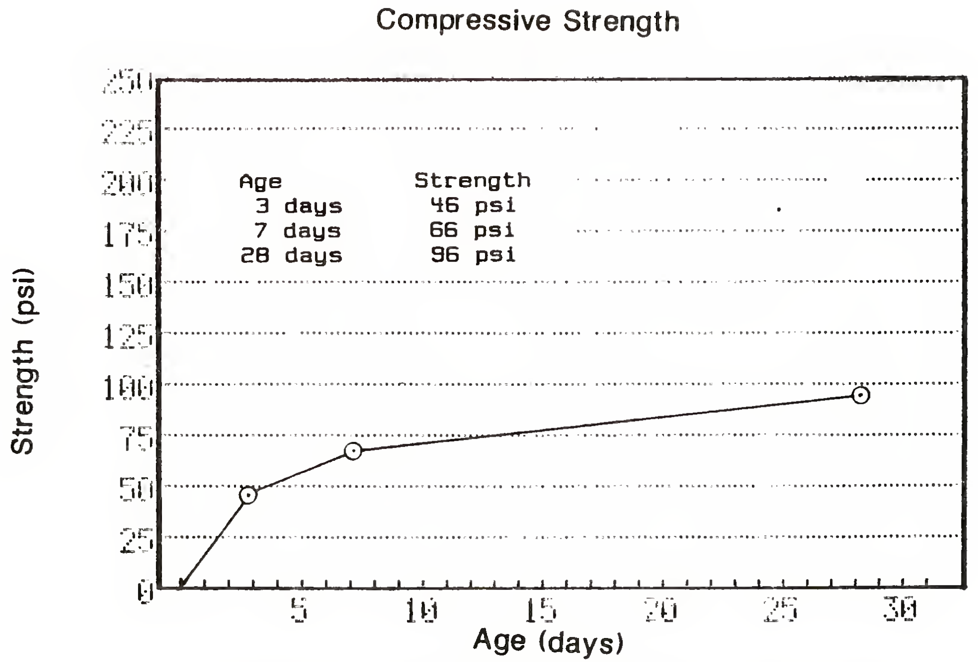

Figure No. 6. Compressive Strength, Mix No. 6a

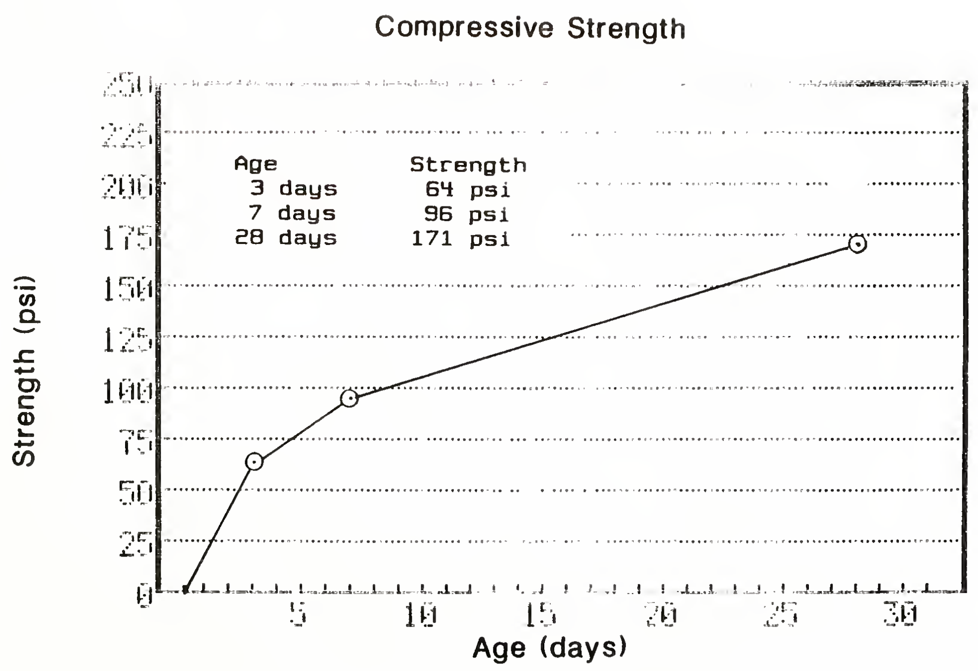

Figure No. 7. Compressive Strength, Mix No. 7

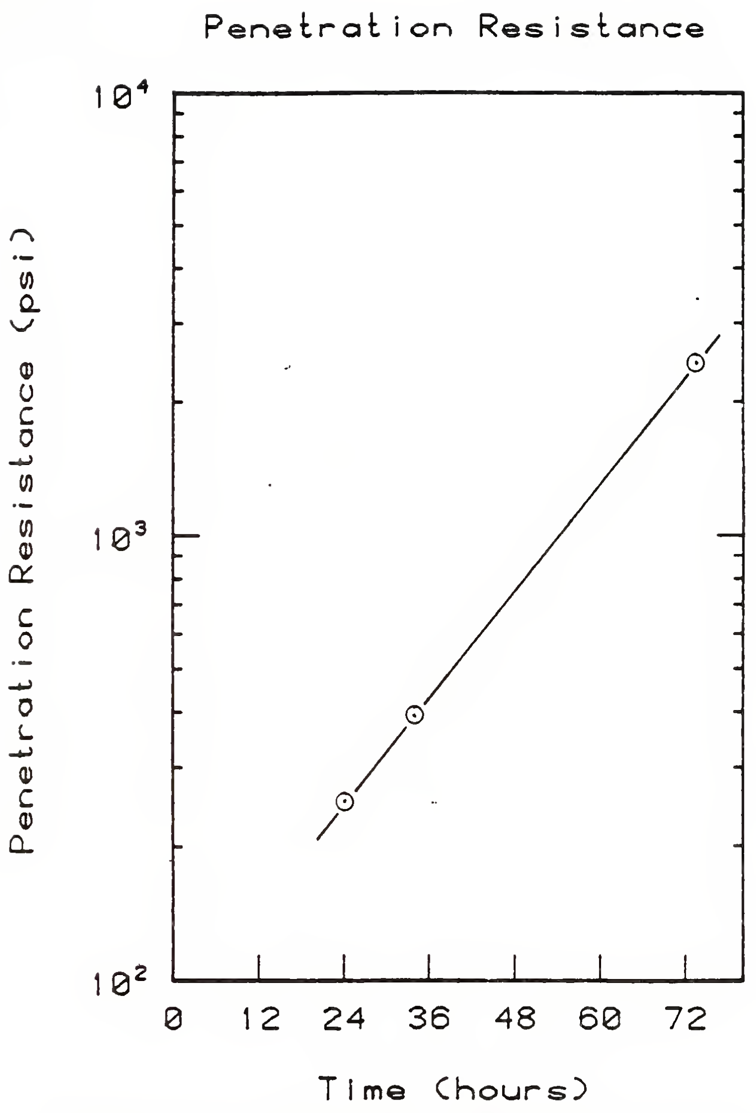

Figure No. 8. Penetration Resistance, Mix No. 1

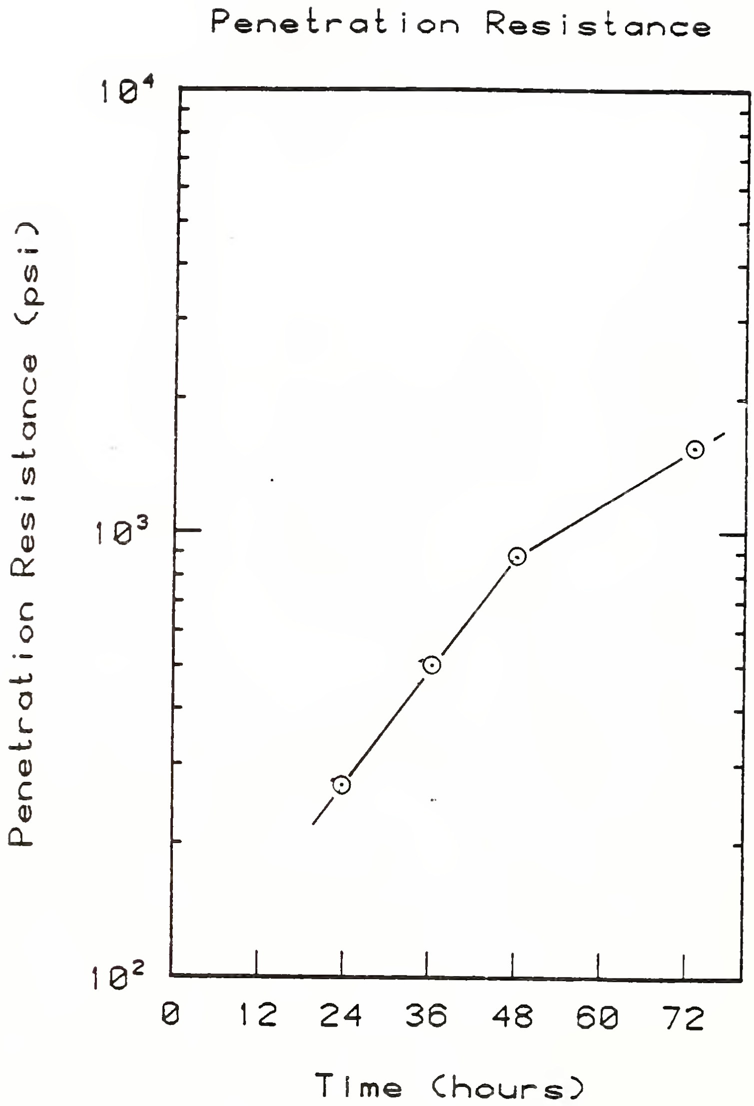

Figure No. 9. Penetration Resistance, Mix No. 2

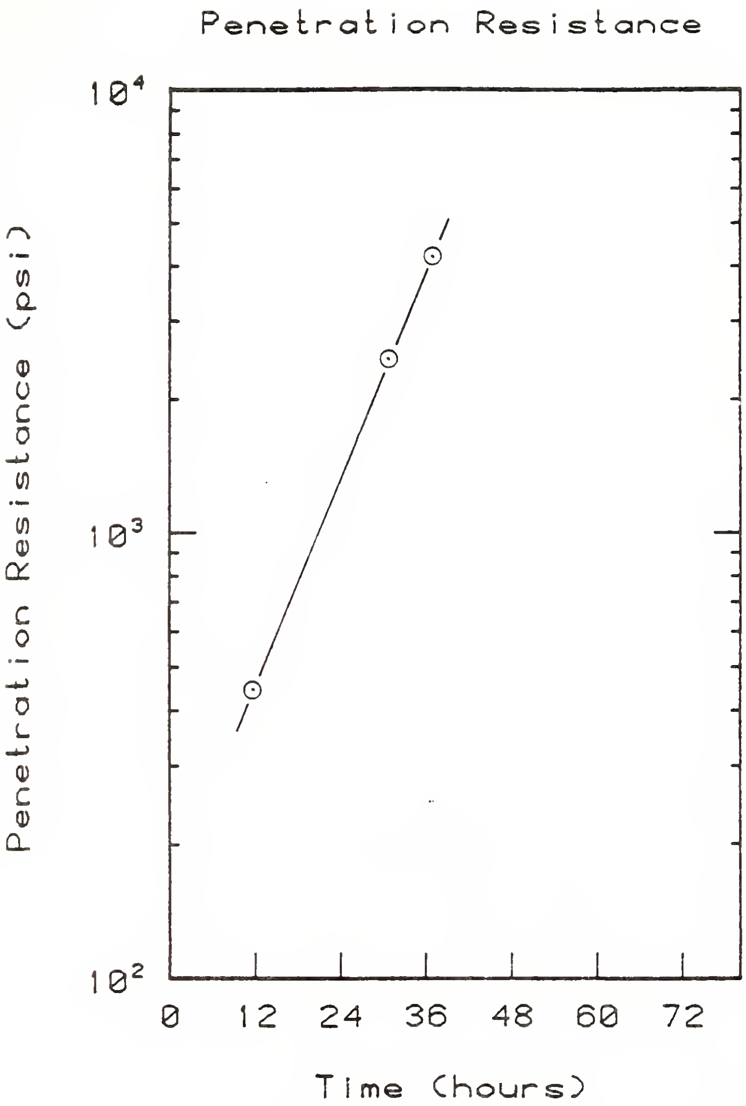

Figure No. 10. Penetration Resistance, Mix No. 3

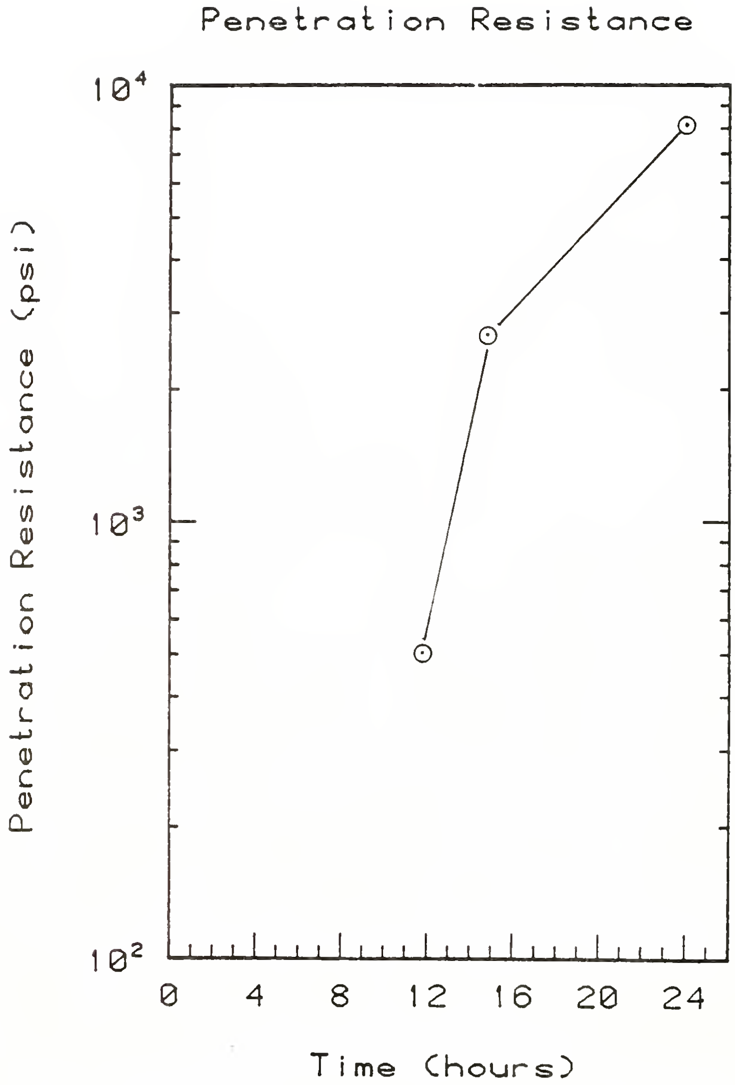

Figure No. 11. Penetration Resistance, Mix No. 4

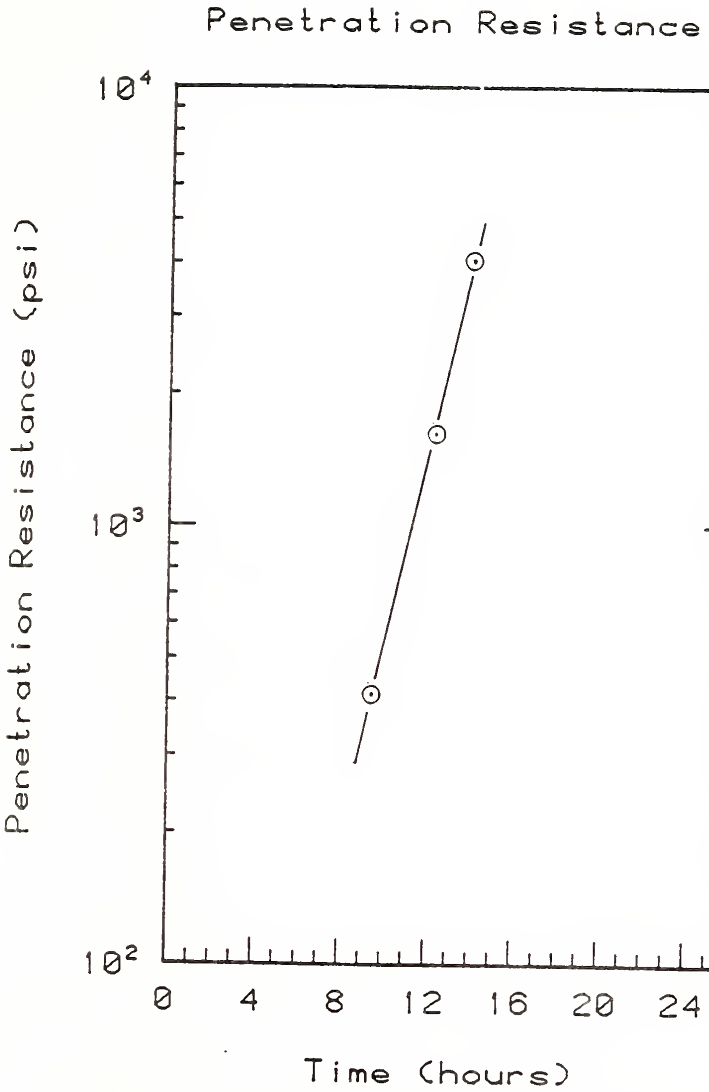

Figure No. 12. Penetration Resistance, Mix No. 5

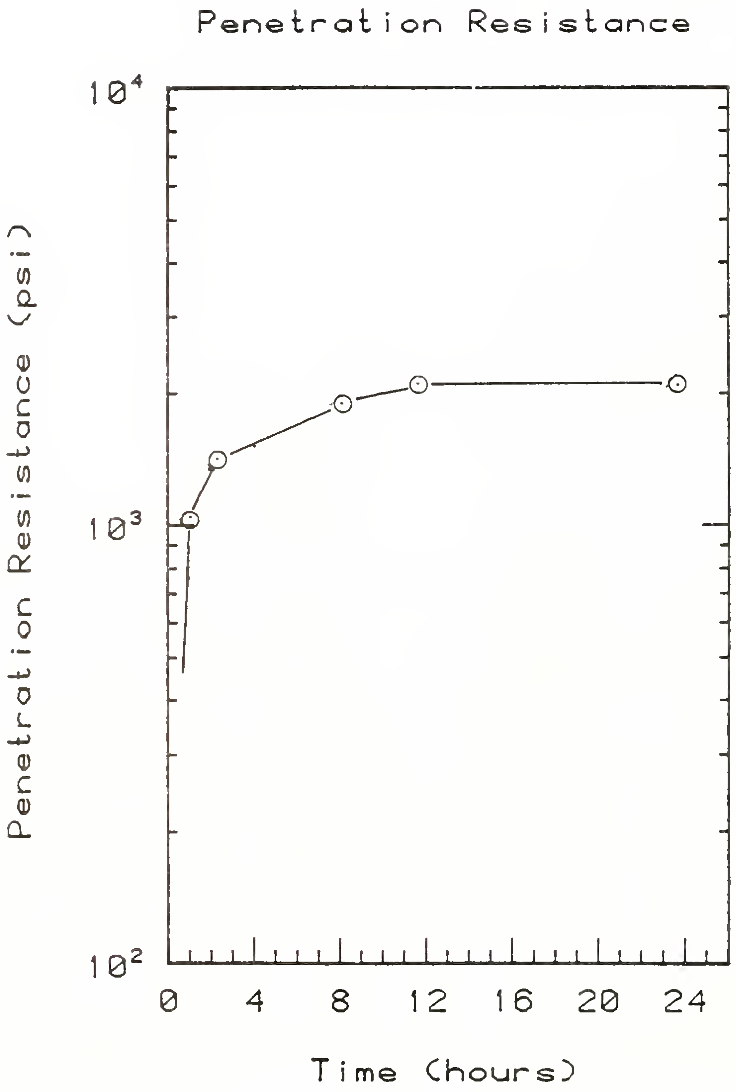

Figure No. 13. Penetration Resistance, Mix No. 6a

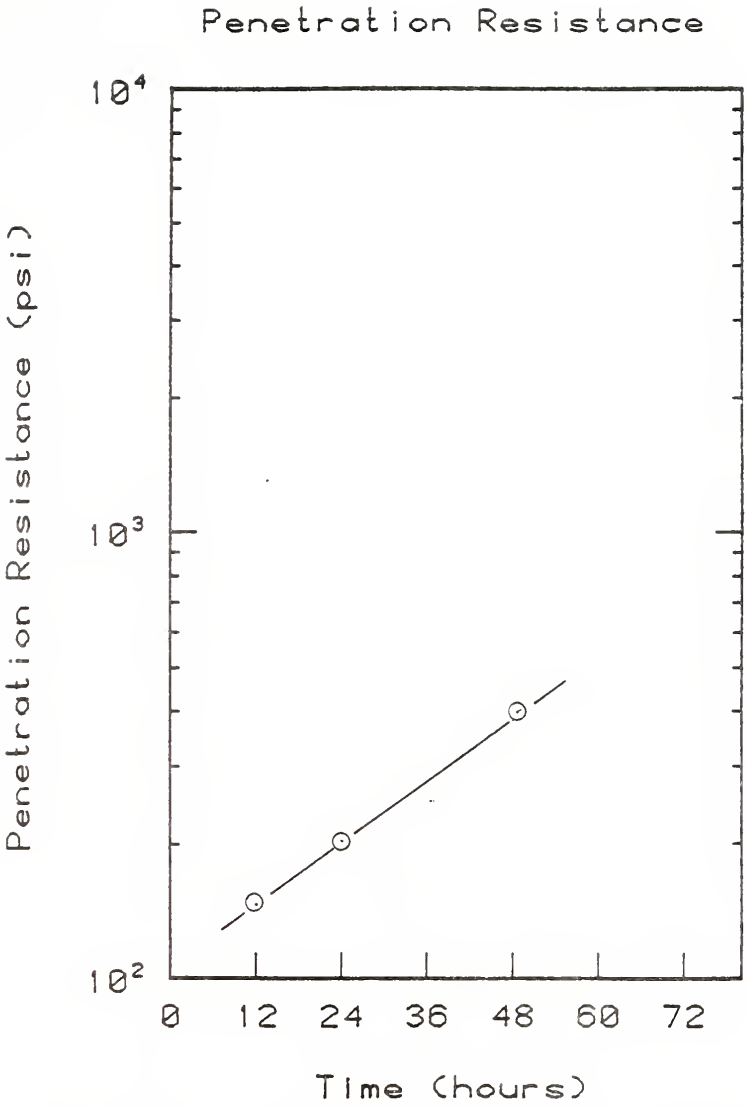

Figure No. 14. Penetration Resistance, Mix No. 6b

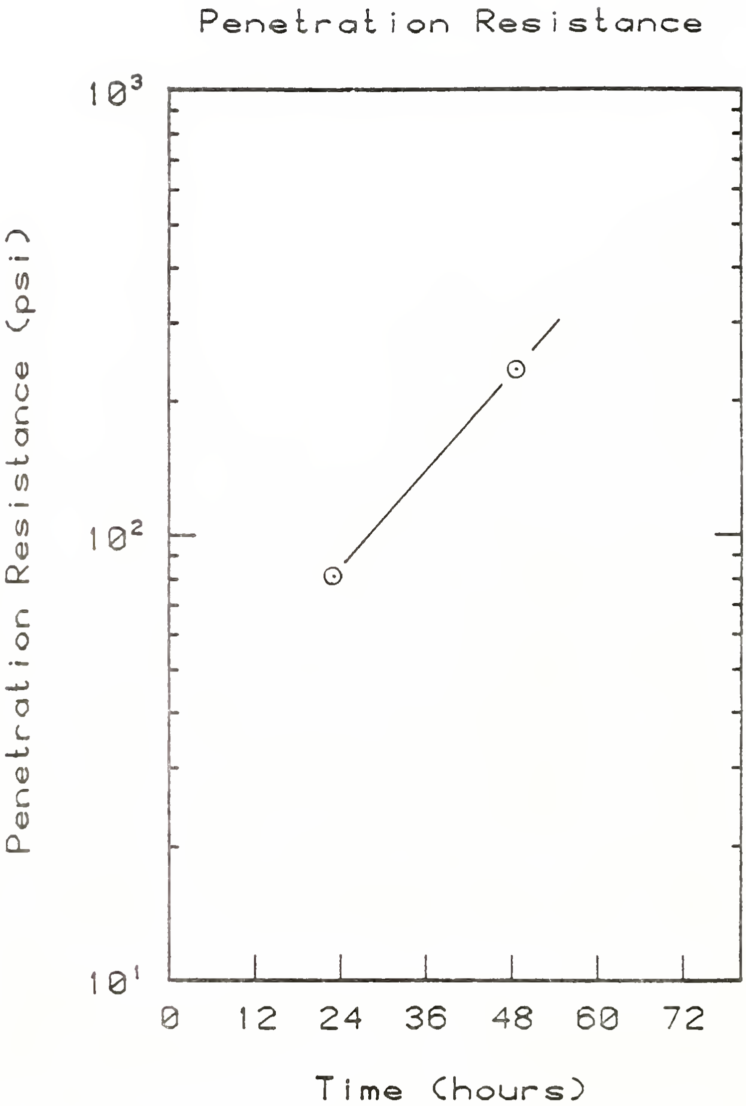

Figure No. 15. Penetration Resistance, Mix No. 7

DISCUSSION

Controlled low strength material (CLSM) is a low strength mortar consisting of cement, sand, and water. It can be modified with such things as fly ash, and chemical admixtures i.e. air entrainers and accelerators. CLSM as a replacement for soil as structural backfill must have certain properties. It must have low strength so that it can be removed easily. It must be able to flow into inaccesible spots and around pipe. It must set up between 4 and 24 hours: any sooner and it could set up in the truck, any later and it becomes economically undesirable. Another special property that can be provided, is a low density, high strength backfill over weak a subgrade soil.

For easy removal with a small backhoe the compressive strength of CLSM should be below 200 psi, preferably in the 100 psi range. The strength is primarily a function of the cement content. The water to cement ratio is so high that any change has only minor effects on the strength. If fly ash is added, the strength goes up, due partially to some pozzolanic effect, but principally because the fly ash - water paste increases the viscosity of the carrier suspension, providing a more uniform consistency.

Controlled low strength mortar should flow well, for easy placement in inaccesible areas. Flow time standards of 13 seconds using ASTM C-939 have been required by some transportation departments. Flow time of less than 35 seconds should be acceptable for most construction. The flowability is a measure of viscosity. It is a function of the water content and the grain size distribution. Too little water, and there is no flow, too much and the mortar will segregate. Fly ash and water form a paste that increases the viscosity of the carrier suspension providing a more uniformly consistent mortar, thereby increasing flowability and decreasing segregation. In areas where fly ash is not available, air entrainment (about 10%) can be used instead.

To be economically feasible CLSM should set up between four and 24 hours. If it sets up too quickly (for example mix 6a) it would set up in the truck. If it sets up too slowly it would slow down construction too much. Accelerators works fine on the high strength mixes, but for the low strength mixes there is not enough cement with which the admixture can react. Class F fly ash slows down the set time. Class C fly ash either sets up in an hour or in one week with only a small change in the amount of fly ash and water content making a large difference. When the mortar with Class C fly ash sets up quickly there is little heat evolved.

Light weight mortar of the same compressive strength as a normal weight low strength mortar will have a lower penetration resistance, because of the increased number of air voids. Penetration resistance standards should be modified in this case. In general penetration resistance is a good indication of early strength for CLSM and could, and perhaps should, be used as a standard test method instead of the compressive strength test.

The choice of a mortar mix for a given application depends on the required strength, strength gain, and economics. In areas that will not require later excavation, high strength mortar is preferable to low. If a faster strength gain is required in the high strength mortar an accelerator can be added. In areas where later excavation may be necessary, the lower strength mix designs are preferable.

Five low strength mix designs were tested. Two of the designs, the accelerated low strength mortar with Class F fly ash, and the low strength mortar with Class C fly ash, are not viable for use in the field. The accelerated low strength mortar does not have any appreciable strength gain over the unaccelerated low strength mortar. The set time of the Class C fly ash mortar is too highly variable with minor changes in the proportioning to be of any use in the field.

The other three low strength mix designs are appropriate for use in the field. They are the low strength mortar with Class F fly ash (Mix No. 1), air entrained low strength mortar (mix No. 3), and light weight low strength mortar (Mix No. 7). The low strength mortar with Class F fly ash is preferable to the air entrained mortar if improved consistency and flow time are desired, and if the availability of a suitable Class F fly ash and the slower set time are not problems. The light weight low strength mortar is for problems such as that replacement of low strength subgrade.

RECOMMENDATIONS

Part of the process of this study was a long preliminary testing of mortars with varying constituents to get the seven final mixes presented in this paper.

Any performance specification for CLSM should be based on the following properties: compressive strength, penetration resistance, and flow time. The purpose of this study was not to define the exact values required for these properties, but to provide general values to be modified with experience from the field. For compressive strength curves and penetration resistance for the model mix designs please see Figures 1 to 15.

The compressive strength of low strength mortar should range between 100 psi and 200 psi at 28 days. High strength mortar should have a minimum compressive strength of 1000 psi at 28 days.

Penetration resistance is a good measure of the early strength of the mortar. The strength should be high enough to allow placement of pavement over the CLSM. Testing in the lab would indicate that a penetration resistance of 600 psi would be strong enough to support pavement placement, but probably not heavy equipment.

A flow time of less than 35 seconds should be acceptable for most construction. Flow time measurement according to ASTM C-939 may not be the best measurement of viscosity for CLSM.

The following recomendations seem reasonable and are based on the results of this study. Adjustments to these mix designs may be appropriate, depending on the materials used and the job characterisics.

Mix No. 1 (low strength mortar with class F fly ash) is recomended for use in areas that are expected to be excavated later, i.e. utility cuts. It should be used where increased flowability and consistancy are required.

Mix No. 3 (air entrained low strength mortar) is recomended for use in areas that are expected to be excavatd later. It should be use where a suitable Class F fly ash is not available and where a slightly accelerated set is required.

Mix No. 4 (high strength mortar with class F fly ash) is recommended for use in areas that will not be excavated later, e.g. bridge abutments. It should be used where a firm, non-settling foundation is required.

Mix No. 5 (accelerated high strength mortar with class F fly ash) is recomended for use in areas that will not be excavated later. It should be used if a accelerated set time is required and the increased cost is not a factor.

Mix No. 7 (low strength light weight mortar) is recomended for use in areas with low strength subgrades, e.g. clay. It should be used as a replacement for the overburden.

It should be remembered that there is a high amount of bleeding possible for most CLSM mixes, and that until the mortar has set up there is a loss of volume as the bleed water works its way up from the body of the placement to the surface. After the motar has set up and the bleed water has been removed there should be no settlement and the next lift can be placed.

CONCLUSIONS

In this study five mix designs of controlled low strength material were developed that can be used in the field. Most construction requirements for municipal or highway structural backfill can be met by one of these mix designs. Controlled low strength material is a economical substitute for soil as a structural backfill in trenches, next to bridge abutments, or any place where compaction is difficult. Mix designs provided in the appendix can be used as a guide for mixes used in the field.

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APPENDICES

Appendix A

Mix Designs for use in the Field

The following mix designs can be adapted for use in the field. To make the mortar first place sand in the mixer followed by the fly ash and cement. Then add the water and any admixtures, i.e. accelerators or air entrainers. Mix until the mortar is consistent, about three minutes. If foam is to be used it should be added at this point with an additional three minutes of mixing. Keep the mixer rotating at a moderate speed, to prevent segregation, until mixer is empty.

Mortar should not be placed on frozen ground or in freezing temperatures. Each stage of placement should be continuous. Filler material should be placed in areas where the mortar is not desired, i.e. next to bridge flanges, or pipe valves.

Low strength mortar with class F fly ash

Mix design for one cubic yard

61	lb. cement
331	lb. fly ash
2859	lb. sand
509	lb. water
3760	lb. total

w/c = 2.70
w/c+f = 1.30

Flow time = greater than 35 sec

Unit weight = 139 pcf

Percentage Bleeding = 27.3%

Set time = 400 psi in 36 hours

Estimated compressive strength

Age	Strength
3 days	20 psi
7 days	30 psi
28 days	80 psi

Air entrained low strength mortar

Mix design for one cubic yard

185 lb.	cement
2673 lb.	sand
500 lb.	water
5.2 oz	MB-VR
3358 lb.	total

w/c = 2.70

Flow time = greater than 35 sec

Unit weight = 125 pcf

Percentage Air = 10%

Percentage Bleeding = 14.3%

Set time = 24 hours for 1300 psi

Estimated compressive strength

Age	Strength
3 days	70 psi
7 days	130 psi
28 days	200 psi

High strength mortar with class F fly ash

Mix design for one cubic yard

195 lb.	cement
572 lb.	fly ash
2673 lb.	sand
488 lb.	water
3723 lb.	total

w/c = 2.50
w/c+f = 0.64

Flow time = 33 sec

Unit weight = 138 pcf

Percentage Bleeding = 15.3%

Set time = 12 hours for 500 psi

Estimated compressive strength

Age	Strength
3 days	300 psi
7 days	500 psi
28 days	1000 psi

Accelerated high strength mortar with class F fly ash

Mix design for one cubic yard

195	lb. cement
572	lb. fly ash
2673	lb. sand
488	lb. water
45.2	oz Pozzolith 122-HE
3723	lb. total

w/c = 2.50
w/c+f = 0.64

Flow time = 31 sec

Unit weight = 139 pcf

Percentage Bleeding = 13.3%

Set time = 12 hours for 1600 psi

Estimated compressive strength

Age	Strength
3 days	360 psi
7 days	550 psi
28 days	1100 psi

Low strength light weight mortar

Mix design for one cubic yard

517	lb.	cement
413	lb.	sand
341	lb.	water
52.6	lb.	foam = 16.85 cft
1324	lb.	total

w/c = 0.66

Flow time = 29 sec

Unit weight = 49 pcf

Percentage Bleeding = none

Set time = 48 hours for 225 psi, firm

Estimated compressive strength

Age	Strength
3 days	65 psi
7 days	95 psi
28 days	175 psi

Appendix B

Tests performed

The test performed include the following:

ASTM C-39	Compressive Strength of Cylindrical Concrete Specimens
ASTM C-939	Flow of Grout for Preplaced Aggregate Concrete (equivalent to Corps of Engineers CRD - 611-80)
ASTM C-403	Time of Setting of Concrete Mixtures by Penetration Resistance
ASTM C-232	Bleeding of Concrete
ASTM C-138	Unit Weight, Yield, and Air Content (Gravimetric) of Concrete

Implementation Report

STUDIES ON CONTROLLED LOW STRENGTH MORTAR

by

W. Kepler

The following suggestions are made as possible ways the results of this report might be implemented.

The aim of this research was to develop suitable mix designs for several controlled low strength mortars (CLSM). The designs so developed are summarized in Appendix A of the report. The chief variables are strength (high, low), unit weight (normal, lightweight), air entrained or not, and with or without fly ash.

These materials are intended to be used in place of soil as structural backfill, primarily in utility cuts and culvert placement. It is recommended that ISHD use these materials in appropriate situations, on a trial basis, to evaluate their field suitability and the applicability of the laboratory results. Probably small amounts should be used at first, and it should be recognized that the mix designs given in the report are intended only as a guide and will probably have to be modified to suit the requirements of the specific use and materials available.

More detailed recommendations, including specific applications for the various mix designs, are given in the RECOMMENDATION section of the report (p. 33-35). It is recommended that the ideas in this section be followed initially and modified as needed for individual projects.

If these materials are found useful for highway construction and repair, a formal specification would be in order, which would incorporate the results of this study as well as subsequent field experience. An ACI committee exists with CLSM as its charge. The activities of this committee should be followed.

COVER DESIGN BY ALDO GIORGINI